2011 Update to The Society of Thoracic Surgeons and the Society of Cardiovascular Anesthesiologists Blood Conservation Clinical Practice Guidelines*

The Society of Thoracic Surgeons Blood Conservation Guideline Task Force:
Victor A. Ferraris, MD, PhD (Chair), Jeremiah R. Brown, PhD, George J. Despotis, MD, John W. Hammon, MD, T. Brett Reece, MD, Sibu P. Saha, MD, MBA, Howard K. Song, MD, PhD, and Ellen R. Clough, PhD

The Society of Cardiovascular Anesthesiologists Special Task Force on Blood Transfusion:
Linda J. Shore-Lesserson, MD, Lawrence T. Goodnough, MD, C. David Mazer, MD, Aryeh Shander, MD, Mark Stafford-Smith, MD, and Jonathan Waters, MD

The International Consortium for Evidence Based Perfusion:
Robert A. Baker, PhD, Dip Perf, CCP (Aus), Timothy A. Dickinson, MS, Daniel J. FitzGerald, CCP, LP, Donald S. Likosky, PhD, and Kenneth G. Shann, CCP

Division of Cardiovascular and Thoracic Surgery, University of Kentucky, Lexington, Kentucky (VAF, SPS), Department of Anesthesiology, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania (JW), Departments of Anesthesiology and Critical Care Medicine, Englewood Hospital and Medical Center, Englewood, New Jersey (AS), Departments of Pathology and Medicine, Stanford University School of Medicine, Stanford, California (LTG), Departments of Anesthesiology and Cardiothoracic Surgery, Montefiore Medical Center, Bronx, New York (LJS-L, KGS), Departments of Anesthesiology, Immunology, and Pathology, Washington University School of Medicine, St. Louis, Missouri (GJD), Dartmouth Institute for Health Policy and Clinical Practice, Section of Cardiology, Dartmouth Medical School, Lebanon, New Hampshire (JRB), Department of Cardiothoracic Surgery, Wake Forest School of Medicine, Winston-Salem, North Carolina (JWH), Department of Anesthesia, St. Michael's Hospital, University of Toronto, Toronto, Ontario (CDM), Cardiac Surgical Research Group, Flinders Medical Centre, South Australia, Australia (RAB), Department of Surgery, Medicine, Community and Family Medicine, and the Dartmouth Institute for Health Policy and Clinical Practice, Dartmouth Medical School, Hanover, New Hampshire (DSL), SpecialtyCare, Nashville, Tennessee (TAD), Department of Cardiac Surgery, Brigham and Women's Hospital, Harvard University, Boston, Massachusetts (DJF), Division of Cardiothoracic Surgery, Oregon Health and Science University Medical Center, Portland, Oregon (HKS), Department of Cardiothoracic Surgery, University of Colorado Health Sciences Center, Aurora, Colorado (TBR), Department of Anesthesiology, Duke University Medical Center, Durham, North Carolina (MS-S), and The Society of Thoracic Surgeons, Chicago, Illinois (ERC)

Background. **Practice guidelines reflect published literature. Because of the ever changing literature base, it is necessary to update and revise guideline recommendations from time to time. The Society of Thoracic Surgeons recommends review and possible update of previously published guidelines at least every three years. This summary is an update of the blood conservation guideline published in 2007.**

Methods. **The search methods used in the current version differ compared to the previously published guideline. Literature searches were conducted using standardized MeSH terms from the National Library of Medicine PUBMED database list of search terms. The following terms comprised the standard baseline search terms for all topics and were connected with the logical 'OR' connector—Extracorporeal circulation (MeSH number E04.292), cardiovascular surgical procedures (MeSH number E04.100), and vascular diseases (MeSH number C14.907). Use of these broad search terms allowed specific topics to be added to the search with the logical 'AND' connector.**

Results. **In this 2011 guideline update, areas of major revision include: 1) management of dual anti-platelet therapy before operation, 2) use of drugs that augment red blood cell volume or limit blood loss, 3) use of blood derivatives including fresh frozen plasma, Factor XIII, leukoreduced red blood cells, platelet plasmapheresis,**

SPECIAL REPORT

*The International Consortium for Evidence Based Perfusion formally endorses these guidelines.

The Society of Thoracic Surgeons Clinical Practice Guidelines are intended to assist physicians and other health care providers in clinical decision-making by describing a range of generally acceptable approaches for the diagnosis, management, or prevention of specific diseases or conditions. These guidelines should not be considered inclusive of all proper methods of care or exclusive of other methods of care reasonably directed at obtaining the same results. Moreover, these guidelines are subject to change over time, without notice. The ultimate judgment regarding the care of a particular patient must be made by the physician in light of the individual circumstances presented by the patient.

For the full text of this and other STS Practice Guidelines, visit http://www.sts.org/resources-publications at the official STS Web site (www.sts.org).

Address correspondence to Dr Ferraris, Division of Cardiothoracic Surgery, University of Kentucky, A301, Kentucky Clinic, 740 S Limestone, Lexington, KY 40536-0284; e-mail: ferraris@earthlink.net.

See Appendix 2 for financial relationship disclosures of authors.

Ann Thorac Surg 2011;91:944–82 • 0003-4975/$36.00
doi:10.1016/j.athoracsur.2010.11.078

recombinant Factor VII, antithrombin III, and Factor IX concentrates, 4) changes in management of blood salvage, 5) use of minimally invasive procedures to limit perioperative bleeding and blood transfusion, 6) recommendations for blood conservation related to extracorporeal membrane oxygenation and cardiopulmonary perfusion, 7) use of topical hemostatic agents, and 8) new insights into the value of team interventions in blood management.

Conclusions. **Much has changed since the previously published 2007 STS blood management guidelines and this document contains new and revised recommendations.**

(Ann Thorac Surg 2011;91:944–82)

1) Executive Summary

Introduction—Statement of the Problem

In the United States, surgical procedures account for transfusion of almost 15 million units of packed red blood cells (PRBC) every year. Despite intense interest in blood conservation and minimizing blood transfusion, the number of yearly transfusions is increasing [1]. At the same time, the blood donor pool is stable or slightly decreased [1, 2]. Donor blood is viewed as a scarce resource that is associated with increased cost of health care and significant risk to patients (http://www.hhs.gov/ophs/bloodsafety/2007nbcus_survey.pdf).

Perioperative bleeding requiring blood transfusion is common during cardiac operations, especially those procedures that require cardiopulmonary bypass (CPB). Cardiac operations consume as much as 10% to 15% of the nation's blood supply, and evidence suggests that this fraction is increasing, largely because of increasing complexity of cardiac surgical procedures. The majority of patients who have cardiac procedures using CPB have sufficient wound clotting after reversal of heparin and do not require transfusion. Nevertheless, CPB increases the need for blood transfusion compared with cardiac procedures done "off-pump" (OPCABG) [3]. Real-world experience based on a large sample of patients entered into The Society of Thoracic Surgeons Adult Cardiac Surgery Database suggests that 50% of patients undergoing cardiac procedures receive blood transfusion [4]. Complex cardiac operations like redo procedures, aortic operations, and implantation of ventricular assist devices require blood transfusion with much greater frequency [4–6]. Increasing evidence suggests that blood transfusion during cardiac procedures portends worse short- and long-term outcomes [7, 8]. Interventions aimed at reducing bleeding and blood transfusion during cardiac procedures are an increasingly important part of quality improvement and are likely to provide benefit to the increasingly complex cohort of patients undergoing these operations.

The Society of Thoracic Surgeons Workforce on Evidence Based Surgery provides recommendations for practicing thoracic surgeons based on available medical evidence. Part of the responsibility of the Workforce on Evidence Based Surgery is to continually monitor published literature and to periodically update recommendations when new information becomes available. This document represents the first revision of a guideline by the Workforce and deals with recent new information on blood conservation associated with cardiac operations. This revision contains new evidence that alters or adds to the 61 previous recommendations that appeared in the 2007 Guideline [9].

Abbreviations and Acronyms

ACS	= acute coronary syndrome
AT	= antithrombin
CABG	= coronary artery bypass graft surgery
CI	= confidence interval
CPB	= cardiopulmonary bypass
ECC	= extracorporeal circuit
ECMO	= extracorporeal membrane oxygenation
EPO	= erythropoietin
FDA	= Food and Drug Administration
FFP	= fresh-frozen plasma
ICU	= intensive care unit
MUF	= modified ultrafiltration
OPCABG	= off-pump coronary artery bypass graft surgery
PCC	= prothrombin complex concentrate
PRBC	= packed red blood cells
PRP	= platelet-rich plasma
r-FVIIa	= recombinant activated factor VII
RR	= relative risk
TEVAR	= thoracic endovascular aortic repair
VAVD	= vacuum-assisted venous drainage
ZBUF	= zero-balanced ultrafiltration

2) Methods Used to Survey Published Literature

The search methods used to survey the published literature changed in the current version compared with the previously published guideline. In the interest of transparency, literature searches were conducted using standardized MeSH terms from the National Library of Medicine PUBMED database list of search terms. The following terms comprised the standard baseline search terms for all topics and were connected with the logical "OR" connector: extracorporeal circulation (MeSH number E04.292 includes extracorporeal membrane oxygenation [ECMO], left heart bypass, hemofiltration, hemoperfusion, and cardiopulmonary bypass), cardiovascular surgical procedures (MeSH number E04.100 includes OPCABG, CABG, myocardial revascularization, all valve operations, and all other operations on the heart), and vascular diseases (MeSH number C14.907 includes dissections, aneurysms of all types including left ventricular aneurysms, and all vascular diseases). Use of

SPECIAL REPORT

these broad search terms allowed specific topics to be added to the search with the logical "AND" connector. This search methodology provided a broad list of generated references specific for the search topic. Only English language articles contributed to the final recommendations. For almost all topics reviewed, only evidence relating to adult patients entered into the final recommendations, primarily because of limited availability of high-quality evidence relating to pediatric patients having cardiac procedures. Members of the writing group, assigned to a specific topic, made recommendations about blood conservation and blood transfusion associated with cardiac operations based on review of important articles obtained using this search technique. The quality of information on a given blood conservation topic allowed assessment of the level of evidence as recommended by the AHA/ACCF Task Force on Practice Guidelines (http://www.americanheart.org/downloadable/heart/12604770597301209Methodology_Manual_for_ACC_AHA_Writing_Committees.pdf).

Writers assigned to the various blood conservation topics wrote and developed new or amended recommendations, but each final recommendation that appears in this revision was approved by at least a two-thirds majority favorable vote from all members of the writing group. Appendix 1 contains the results of the voting for each recommendation, and explains any major individual dissensions. Appendix 2 documents the authors' potential conflicts of interest and industry disclosures.

3) Synopsis of New Recommendations for Blood Conservation

a) Risk Assessment

Not all patients undergoing cardiac procedures have equal risk of bleeding or blood transfusion. An important part of blood resource management is recognition of patients' risk of bleeding and subsequent blood transfusion. In the STS 2007 blood conservation guideline, an extensive review of the literature revealed three broad risk categories for perioperative bleeding or blood transfusion: (1) advanced age, (2) decreased preoperative red blood cell volume (small body size or preoperative anemia or both), and (3) emergent or complex operations (redo procedures, non-CABG operations, aortic surgery, and so forth). Unfortunately, the literature does not provide a good method of assigning relative value to these three risk factors. There is almost no evidence in the literature to stratify blood conservation interventions by patient risk category. Nonetheless, logic suggests that patients at highest risk for bleeding are most likely to benefit from the most aggressive blood management practices, especially since the highest risk patients consume the majority of blood resources.

There is one major risk factor that does not easily fit into any of these three major risk categories, and that is the patient who is unwilling to accept blood transfusion for religious reasons (eg, Jehovah's Witness). Special interventions are available for Jehovah's Witness patients, and the new or revised recommendations include options for these patients. Even within the Jehovah's Witness population, there are differences in willingness to accept blood conservation interventions (see below), so it is an oversimplification to have only one category for this population.

b) Recommendations

Table 1 summarizes the new and revised blood conservation recommendations for patients undergoing cardiac operations based on available evidence. The full text that describes the evidence base behind each of these recommendations is available in the following sections.

Table 2 is a summary of the previously published 2007 guideline recommendations that the writing group feels still have validity and provide meaningful suggestions for blood conservation.

4) Major Changes or Additions

Certain features of blood conservation and management of blood resources stand out based on recently available evidence. Preoperative risk assessment is a necessary starting point. Of the three major preoperative patient risk factors listed above, the patients who are easiest to address are those with low red blood cell volume, either from preoperative anemia or from small body size. Two persistent features of perioperative blood conservation are the need for minimization of hemodilution during CPB and the effective treatment of preoperative anemia. Reduced patient red blood cell volume (fraction of red cells multiplied by blood volume) is a convenient measure of patient risk that correlates with bleeding and blood transfusion in patients with preoperative anemia or small body size. In simplistic terms, red blood cell volume is an index of the red cell reserve that is likely to be depleted by operative intervention. Significant revisions of the blood conservation guidelines aim at reducing hemodilution and conserving preoperative patient red cell volume. These include use of preoperative erythropoietin, minimized CPB circuits with reduced priming volume (minicircuits), normovolemic hemodilution, salvage of blood from the CPB circuit, modified ultrafiltration, and microplegia. Best practice suggests that use of multimodality interventions aimed at preserving red blood cell volume, whether by increasing red cell volume preoperatively with erythrocyte stimulating agents or by limiting hemodilution during operation, offers the best chance of preservation of hemostatic competence and of reduced transfusion.

An equally important part of preoperative risk assessment is identification and management of preoperative antiplatelet and anticoagulant drug therapy. Persistent evidence supports the discontinuation of drugs that inhibit the P2Y12 platelet binding site before operation, but there is wide variability in patient response to drug dosage (especially with clopidogrel). Newer P2Y12 inhibitors are more potent than clopidogrel and differ in their pharmacodynamic properties. Point-of-care testing may

SPECIAL REPORT

Table 1. New and Revised 2011 Recommendations for Blood Conservation in Patients Undergoing Cardiac Procedures With Differing Risks

Blood Conservation Intervention	Class of Recommendation (Level of Evidence)
Preoperative interventions	
Drugs that inhibit the platelet P2Y12 receptor should be discontinued before operative coronary revascularization (either on pump or off pump), if possible. The interval between drug discontinuation and operation varies depending on the drug pharmacodynamics, but may be as short as 3 days for irreversible inhibitors of the P2Y12 platelet receptor.	I (B)
Point-of-care testing for platelet adenosine diphosphate responsiveness might be reasonable to identify clopidogrel nonresponders who are candidates for early operative coronary revascularization and who may not require a preoperative waiting period after clopidogrel discontinuation.	IIb (C)
Routine addition of P2Y12 inhibitors to aspirin therapy early after coronary artery bypass graft (CABG) may increase the risk of reexploration and subsequent operation and is not indicated based on available evidence except in those patients who satisfy criteria for ACC/AHA guideline-recommended dual antiplatelet therapy (eg, patients presenting with acute coronary syndromes or those receiving recent drug eluting coronary stents).	III (B)
It is reasonable to use preoperative erythropoietin (EPO) plus iron, given several days before cardiac operation, to increase red cell mass in patients with preoperative anemia, in candidates for operation who refuse transfusion (eg, Jehovah's Witness), or in patients who are at high risk for postoperative anemia. However, chronic use of EPO is associated with thrombotic cardiovascular events in renal failure patients suggesting caution for this therapy in individuals at risk for such events (eg, coronary revascularization patients with unstable symptoms).	IIa (B)
Recombinant human erythropoietin (EPO) may be considered to restore red blood cell volume in patients also undergoing autologous preoperative blood donation before cardiac procedures. However, no large-scale safety studies for use of this agent in cardiac surgical patients are available, and must be balanced with the potential risk of thrombotic cardiovascular events (eg, coronary revascularization patients with unstable symptoms).	IIb (A)
Drugs used for intraoperative blood management	
Lysine analogues—epsilon-aminocaproic acid (Amicar) and tranexamic acid (Cyklokapron)—reduce total blood loss and decrease the number of patients who require blood transfusion during cardiac procedures and are indicated for blood conservation.	I (A)
High-dose (Trasylol, 6 million KIU) and low-dose (Trasylol, 1 million KIU) aprotinin reduce the number of adult patients requiring blood transfusion, total blood loss, and reexploration in patients undergoing cardiac surgery but are not indicated for routine blood conservation because the risks outweigh the benefits. High-dose aprotinin administration is associated with a 49% to 53% increased risk of 30-day death and 47% increased risk of renal dysfunction in adult patients. No similar controlled data are available for younger patient populations including infants and children.	III (A)
Blood derivatives used in blood management	
Plasma transfusion is reasonable in patients with serious bleeding in context of multiple or single coagulation factor deficiencies when safer fractionated products are not available.	IIa (B)
For urgent warfarin reversal, administration of prothrombin complex concentrate (PCC) is preferred but plasma transfusion is reasonable when adequate levels of factor VII are not present in PCC.	IIa (B)
Transfusion of plasma may be considered as part of a massive transfusion algorithm in bleeding patients requiring substantial amounts of red-blood cells. (Level of evidence B)	IIb (B)
Prophylactic use of plasma in cardiac operations in the absence of coagulopathy is not indicated, does not reduce blood loss and exposes patients to unnecessary risks and complications of allogeneic blood component transfusion.	III (A)
Plasma is not indicated for warfarin reversal in the absence of bleeding.	III (A)
Use of factor XIII may be considered for clot stabilization after cardiac procedures requiring cardiopulmonary bypass when other routine blood conservation measures prove unsatisfactory in bleeding patients.	IIb (C)
When allogeneic blood transfusion is needed, it is reasonable to use leukoreduced donor blood, if available. Benefits of leukoreduction may be more pronounced in patients undergoing cardiac procedures.	IIa (B)
Use of intraoperative platelet plasmapheresis is reasonable to assist with blood conservation strategies as part of a multimodality program in high-risk patients if an adequate platelet yield can be reliably obtained.	IIa (A)
Use of recombinant factor VIIa concentrate may be considered for the management of intractable nonsurgical bleeding that is unresponsive to routine hemostatic therapy after cardiac procedures using cardiopulmonary bypass (CPB).	IIb (B)
Antithrombin III (AT) concentrates are indicated to reduce plasma transfusion in patients with AT mediated heparin resistance immediately before cardiopulmonary bypass.	I (A)
Administration of antithrombin III concentrates is less well established as part of a multidisciplinary blood management protocol in high-risk patients who may have AT depletion or in some, but not all, patients who are unwilling to accept blood products for religious reasons.	IIb (C)

Continued

Table 1. Continued

Blood Conservation Intervention	Class of Recommendation (Level of Evidence)
Use of factor IX concentrates, or combinations of clotting factor complexes that include factor IX, may be considered in patients with hemophilia B or who refuse primary blood component transfusion for religious reasons (eg, Jehovah's Witness) and who require cardiac operations.	IIb (C)
Blood salvage interventions	
In high-risk patients with known malignancy who require CPB, blood salvage using centrifugation of salvaged blood from the operative field may be considered since substantial data supports benefit in patients without malignancy and new evidence suggests worsened outcome when allogeneic transfusion is required in patients with malignancy.	IIb (B)
Consensus suggests that some form of pump salvage and reinfusion of residual pump blood at the end of CPB is reasonable as part of a blood management program to minimize blood transfusion.	IIa (C)
Centrifugation of pump-salvaged blood, instead of direct infusion, is reasonable for minimizing post-CPB allogeneic red blood cell (RBC) transfusion.	IIa (A)
Minimally invasive procedures	
Thoracic endovascular aortic repair (TEVAR) of descending aortic pathology reduces bleeding and blood transfusion compared with open procedures and is indicated in selected patients.	I (B)
Off-pump operative coronary revascularization (OPCABG) is a reasonable means of blood conservation, provided that emergent conversion to on-pump CABG is unlikely and the increased risk of graft closure is considered in weighing risks and benefits.	IIa (A)
Perfusion interventions	
Routine use of a microplegia technique may be considered to minimize the volume of crystalloid cardioplegia administered as part of a multimodality blood conservation program, especially in fluid overload conditions like congestive heart failure. However, compared with 4:1 conventional blood cardioplegia, microplegia does not significantly impact RBC exposure.	IIb (B)
Extracorporeal membrane oxygenation (ECMO) patients with heparin-induced thrombocytopenia should be anticoagulated using alternate nonheparin anticoagulant therapies such as danaparoid or direct thrombin inhibitors (eg, lepirudin, bivalirudin or argatroban).	I (C)
Minicircuits (reduced priming volume in the minimized CPB circuit) reduce hemodilution and are indicated for blood conservation, especially in patients at high risk for adverse effects of hemodilution (eg, pediatric patients and Jehovah's Witness patients).	I (A)
Vacuum-assisted venous drainage in conjunction with minicircuits may prove useful in limiting bleeding and blood transfusion as part of a multimodality blood conservation program.	IIb (C)
Use of biocompatible CPB circuits may be considered as part of a multimodality program for blood conservation.	IIb (A)
Use of modified ultrafiltration is indicated for blood conservation and reducing postoperative blood loss in adult and pediatric cardiac operations using CPB.	I (A)
Benefit of the use of conventional or zero balance ultrafiltration is not well established for blood conservation and reducing postoperative blood loss in adult cardiac operations.	IIb (A)
Available leukocyte filters placed on the CPB circuit for leukocyte depletion are not indicated for perioperative blood conservation and may prove harmful by activating leukocytes during CPB.	III (B)
Topical hemostatic agents	
Topical hemostatic agents that employ localized compression or provide wound sealing may be considered to provide local hemostasis at anastomotic sites as part of a multimodal blood management program.	IIb (C)
Antifibrinolytic agents poured into the surgical wound after CPB are reasonable interventions to limit chest tube drainage and transfusion requirements after cardiac operations using CPB.	IIa (B)
Management of blood resources	
Creation of multidisciplinary blood management teams (including surgeons, perfusionists, nurses, anesthesiologists, intensive care unit care providers, housestaff, blood bankers, cardiologists, etc.) is a reasonable means of limiting blood transfusion and decreasing perioperative bleeding while maintaining safe outcomes.	IIa (B)

ACC = American College of Cardiology; AHA = American Heart Association.

help identify patients with incomplete drug response who can safely undergo urgent operations.

There is no substitute for good operative technique, but new evidence suggests that adjunctive topical interventions that supplement local hemostasis are reasonable. An emerging body of literature suggests that topical agents, especially topical antifibrinolytic agents, limit bleeding in the surgical wound. These agents are especially important since abnormalities in postoperative hemostasis start with activation of tissue factor and factor VII in the surgical wound [10]. Topical agents can potentially interrupt the cascade of hemostatic abnormalities closer to the source as opposed to replacement therapy added after the hemostatic insult has occurred.

Table 2. Recommendations From Previously Published Blood Conservation Guidelines With Persistent Support in the Current Medical Literature [9]

Recommendation	Class
Preoperative interventions	
Preoperative identification of high-risk patients (advanced age, preoperative anemia, small body size, noncoronary artery bypass graft or urgent operation, preoperative antithrombotic drugs, acquired or congenital coagulation/clotting abnormalities and multiple patient comorbidities) should be performed, and all available preoperative and perioperative measures of blood conservation should be undertaken in this group as they account for the majority of blood products transfused. (Level of evidence A)	I
Preoperative hematocrit and platelet count are indicated for risk prediction and abnormalities in these variables are amenable to intervention. (Level of evidence A)	I
Preoperative screening of the intrinsic coagulation system is not recommended unless there is a clinical history of bleeding diathesis. (Level of evidence B)	III
Patients who have thrombocytopenia ($<$50,000/mm^2), who are hyperresponsive to aspirin or other antiplatelet drugs as manifested by abnormal platelet function tests or prolonged bleeding time, or who have known qualitative platelet defects represent a high-risk group for bleeding. Maximum blood conservation interventions during cardiac procedures are reasonable in these high-risk patients. (Level of evidence B)	IIa
It is reasonable to discontinue low-intensity antiplatelet drugs (eg, aspirin) only in purely elective patients without acute coronary syndromes before operation with the expectation that blood transfusion will be reduced. (Level of evidence A)	IIa
Most high-intensity antithrombotic and antiplatelet drugs (including adenosine diphosphate-receptor inhibitors, direct thrombin inhibitors, low molecular weight heparins, platelet glycoprotein inhibitors, tissue-type plasminogen activator, streptokinase) are associated with increased bleeding after cardiac operations. Discontinuation of these medications before operation may be considered to decrease minor and major bleeding events. The timing of discontinuation depends on the pharmacodynamic half-life for each agent as well as the potential lack of reversibility. Unfractionated heparin is the notable exception to this recommendation and is the only agent which either requires discontinuation shortly before operation or not at all. (Level of evidence C)	IIb
Alternatives to laboratory blood sampling (eg, oximetry instead of arterial blood gasses) are reasonable means of blood conservation before operation. (Level of evidence B)	IIa
Screening preoperative bleeding time may be considered in high-risk patients, especially those who receive preoperative antiplatelet drugs. (Level of evidence B)	IIb
Devices aimed at obtaining direct hemostasis at catheterization access sites may be considered for blood conservation if operation is planned within 24 hours. (Level of evidence C)	IIb
Transfusion triggers	
Given that the risk of transmission of known viral diseases with blood transfusion is currently rare, fears of viral disease transmission should not limit administration of INDICATED blood products. (This recommendation only applies to countries/blood banks where careful blood screening exists.) (Level of evidence C)	IIa
Transfusion is unlikely to improve oxygen transport when the hemoglobin concentration is greater than 10 g/dL and is not recommended. (Level of evidence C)	III
With hemoglobin levels below 6 g/dL, red blood cell transfusion is reasonable since this can be life-saving. Transfusion is reasonable in most postoperative patients whose hemoglobin is less than 7 g/dL but no high level evidence supports this recommendation. (Level of evidence C)	IIa
It is reasonable to transfuse nonred-cell hemostatic blood products based on clinical evidence of bleeding and preferably guided by point-of-care tests that assess hemostatic function in a timely and accurate manner. (Level of evidence C)	IIa
During cardiopulmonary bypass (CPB) with moderate hypothermia, transfusion of red cells for hemoglobin $\leq$6 g/dL is reasonable except in patients at risk for decreased cerebral oxygen delivery (ie, history of cerebrovascular attack, diabetes, cerebrovascular disease, carotid stenosis) where higher hemoglobin levels may be justified. (Level of evidence C)	IIa
In the setting of hemoglobin values exceeding 6 g/dL while on CPB, it is reasonable to transfuse red cells based on the patient's clinical situation, and this should be considered as the most important component of the decision making process. Indications for transfusion of red blood cells in this setting are multifactorial and should be guided by patient-related factors (ie, age, severity of illness, cardiac function, or risk for critical end-organ ischemia), the clinical setting (massive or active blood loss), and laboratory or clinical parameters (eg, hematocrit, SVO_2, electrocardiogram, or echocardiographic evidence of myocardial ischemia etc.). (Level of evidence C)	IIa
It is reasonable to transfuse nonred-cell hemostatic blood products based on clinical evidence of bleeding and preferably guided by specific point-of-care tests that assess hemostatic function in a timely and accurate manner. (Level of evidence C)	IIa
It may be reasonable to transfuse red cells in certain patients with critical noncardiac end-organ ischemia (eg, central nervous system and gut) whose hemoglobin levels are as high as 10 g/dL but more evidence to support this recommendation is required. (Level of evidence C)	IIb
In patients on CPB with risk for critical end-organ ischemia/injury, transfusion to keep the hemoglobin $\geq$ 7 g/dL may be considered. (Level of evidence C)	IIb
Drugs used for intraoperative blood management	
Use of 1-deamino-8-D-arginine vasopressin (DDAVP) may be reasonable to attenuate excessive bleeding and transfusion in certain patients with demonstrable and specific platelet dysfunction known to respond to this agent (eg, uremic or CPB-induced platelet dysfunction, type I von Willebrand's disease). (Level of evidence B)	IIb

Continued

Table 2. Continued

Recommendation	Class
Routine prophylactic use of DDAVP is not recommended to reduce bleeding or blood transfusion after cardiac operations using CPB. (Level of evidence A)	III
Dipyridamole is not indicated to reduce postoperative bleeding, is unnecessary to prevent graft occlusion after coronary artery bypass grafting, and may increase bleeding risk unnecessarily. (Level of evidence B)	III
Blood salvage interventions	
Routine use of red cell salvage using centrifugation is helpful for blood conservation in cardiac operations using CPB. (Level of evidence A)	I
During CPB, intraoperative autotransfusion, either with blood directly from cardiotomy suction or recycled using centrifugation to concentrate red cells, may be considered as part of a blood conservation program. (Level of evidence C)	IIb
Postoperative mediastinal shed blood reinfusion using mediastinal blood processed by centrifugation may be considered for blood conservation when used in conjunction with other blood conservation interventions. Washing of shed mediastinal blood may decrease lipid emboli, decrease the concentration of inflammatory cytokines, and reinfusion of washed blood may be reasonable to limit blood transfusion as part of a multimodality blood conservation program. (Level of evidence B)	IIb
Direct reinfusion of shed mediastinal blood from postoperative chest tube drainage is not recommended as a means of blood conservation and may cause harm. (Level of evidence B)	III
Perfusion interventions	
Open venous reservoir membrane oxygenator systems during cardiopulmonary bypass may be considered for reduction in blood utilization and improved safety. (Level of evidence C)	IIb
All commercially available blood pumps provide acceptable blood conservation during CPB. It may be preferable to use centrifugal pumps because of perfusion safety features. (Level of evidence B)	IIb
In patients requiring longer CPB times (>2 to 3 hours), maintenance of higher and/or patient-specific heparin concentrations during CPB may be considered to reduce hemostatic system activation, reduce consumption of platelets and coagulation proteins, and to reduce blood transfusion. (Level of evidence B)	IIb
Use either protamine titration or empiric low dose regimens (eg, 50% of total heparin dose) to lower the total protamine dose and lower the protamine/heparin ratio at the end of CPB may be considered to reduce bleeding and blood transfusion requirements. (Level of evidence B)	IIb
The usefulness of low doses of systemic heparinization (activated clotting time ~300 s) is less well established for blood conservation during CPB but the possibility of underheparinization and other safety concerns have not been well studied. (Level of evidence B)	IIb
Acute normovolemic hemodilution may be considered for blood conservation but its usefulness is not well established. It could be used as part of a multipronged approach to blood conservation. (Level of evidence B)	IIb
Retrograde autologous priming of the CPB circuit may be considered for blood conservation. (Level of evidence B)	IIb
Postoperative care	
A trial of therapeutic positive end-expiratory pressure (PEEP) to reduce excessive postoperative bleeding is less well established. (Level of evidence B)	IIb
Use of prophylactic PEEP to reduce bleeding postoperatively is not effective. (Level Evidence B)	III
Management of blood resources	
A multidisciplinary approach involving multiple stakeholders, institutional support, enforceable transfusion algorithms supplemented with point-of-care testing, and all of the already mentioned efficacious blood conservation interventions limits blood transfusion and provides optimal blood conservation for cardiac operations. (Level of evidence A)	I
A comprehensive integrated, multimodality blood conservation program, using evidence based interventions in the intensive care unit, is a reasonable means to limit blood transfusion. (Level of evidence B)	IIa
Total quality management, including continuous measurement and analysis of blood conservation interventions as well as assessment of new blood conservation techniques, is reasonable to implement a complete blood conservation program. (Level of evidence B)	IIa

Minimally invasive procedures, especially implantation of aortic endografts, offer significant savings in blood product utilization. Implantation of aortic endografts for aortic disease is a major advance in blood conservation for a very complex and high-risk group of patients. Similarly, a body of evidence suggests that off-pump procedures limit bleeding and blood transfusion in a select group of patients undergoing coronary revascularization without the use of CPB (OPCABG). However, because of concerns about graft patency in OPCABG procedures [11], the body of evidence to support routine OPCABG for blood conservation during coronary revascularization is not as robust as for aortic endografts.

Finally, the management of blood resources is an important component of blood conservation. Evidence suggests that a multidisciplinary team made up of a broad base of stakeholders provides better utilization of blood resources, while preserving quality outcomes, than does a single decision maker who makes transfusion decisions about blood conservation in bleeding patients. Many decisions about transfusion are not made by surgeons. Recognizing the multitude of practitioners who participate in the transfusion decision is an important step in managing valuable blood resources. Evidence suggests that teams make better decisions about blood transfusion than do individuals. Furthermore, massive